ELECTRON BEAM ANALYSIS OF MICROMETEOROIDS CAPTURED IN AEROGEL AS STARDUST ANALOGUES. G. A. Graham[1*], J. Sheffield-Parker[2], J. P. Bradley[1*], A.T. Kearsley[3], Z.R. Dai[1*], S.C. Mayo[4], N. Teslich[1*], C. Snead[5*], A.J. Westphal[5*] and H. Ishii[1*], [1]IGPP, Lawrence Livermore National Laboratory, Livermore CA 94551, USA (graham42@llnl.gov), [2]XRT Ltd, Port Melbourne, VIC 3170, Australia, [3]Mineralogy Department, Natural History Museum, London, SW7 5BD, UK, [4]CSIRO,Clayton, VIC 3169, Australia, [5]Space Sciences laboratory, UC Berkeley, Berkeley, CA 94720, USA, [*]BayPAC (Bay Area Particle Analysis Consortium) members.

Introduction: In January 2004, NASA's Stardust spacecraft passed through the tail of Comet 81P/Wild-2 [1]. The on-board dust flux monitor instrument indicated that numerous micro- and nano-meter sized cometary dust particles were captured by the dedicated silica aerogel capture cell [2]. The collected cometary particles will be returned to Earth in January 2006 [3]. Current Stardust analogues are: (i) Light-gas-gun accelerated individual mineral grains and carbonaceous meteoritic material in aerogels at the Stardust encounter velocity ca.~ 6 km/s [e.g. 4-5]. (ii) Aerogels exposed in low-Earth orbit (LEO) containing preserved cosmic dust grains [6-7]. Studies of these impacts offer insight into the potential state of the captured cometary dust by Stardust [7] and the suitability of various analytical techniques [e.g. 8-9]. A number of papers have discussed the application of sophisticated synchrotron analytical techniques to analyze Stardust particles [e.g. 10-12]. Yet much of the understanding gained on the composition and mineralogy of interplanetary dust particles (IDPs) has come from electron microscopy studies [e.g. 13-15]. Here we discuss the application of scanning electron microscopy (SEM) for Stardust during the preliminary phase of post-return investigations.

Materials: Impact tracks were extracted from 9.6 cm^2 silica aerogel tiles (0.02 g/cm^2) from NASA's Orbital Debris Collector (ODC) experiment [6] using micro-needles [16] and microblades [17]. To insure an extraterrestrial origin, only impact tracks associated with a so-called "chondritic swarm impact event" have been investigated in this study [6].

Imaging & Analysis: For Stardust, the critical first step of any preliminary examination (PE) will be the location of preserved cometary debris within the impact tracks. Initally this phase of PE can be performed using light microscopy. However if the impact tracks contain highly fragmented micron to sub-micron scale debris, it will be difficult to discriminate between "real" debris and condensed silica aerogel generated during hypervelocity capture. A further complication is that the optical transparency of the Stardust aerogel may have deteriorated during the mission lifetime. As an alternative to light microscopy, X-ray imaging techniques have been evaluated [18]. These techniques have limited use as they may not have the spatial resolution required by Stardust [18].

X-ray Phase Contrast Ultramicroscopy. Recent developments in X-ray projection microscopy now enable phase contrast X-ray imaging to be achieved using a field-emission (FESEM) instrument fitted with a direct detection X-ray CCD [19]. The technique utilizes both absorption and phase contrast imaging and is capable of imaging low density/weakly absorbing materials with a resolution of approximately 100nm. To evaluate the technique, an aerogel keystone mounted on a silicon microforklift was examined in an XL30 FESEM fitted with an X-ray ultraMicroscope (XuM) detector manufactured by XRT Ltd (www.xrt.com.au). Initially phase contrast images were acquired at low magnifications. From the series of acquired images, a 3D rendering of the sample was generated (Fig. 1).

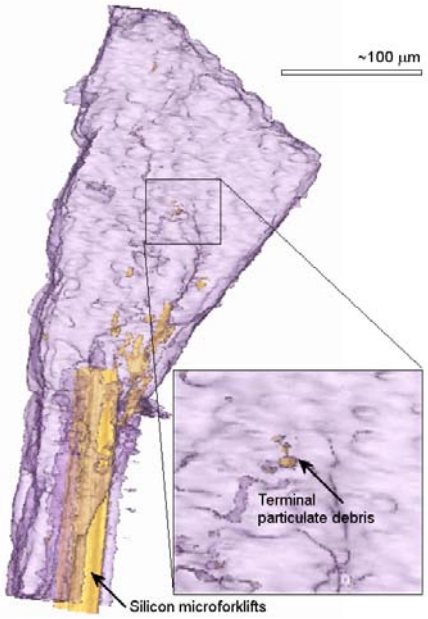

Fig 1: (a) 3D Tomographic rendering of the keystone. The higher density material of the silicon microforklifts and the remnants of the chondritic swarm debris are shown in yellow.

Both the phase-contrast and tomographic images identify the presence of a number of particulates within the main cavity of the impact. Futher higher-resolution imaging and subsequent post-image processing using phase retrieval techniques have resolved individual particulates, ~1.2μm in diameter (Fig.2).

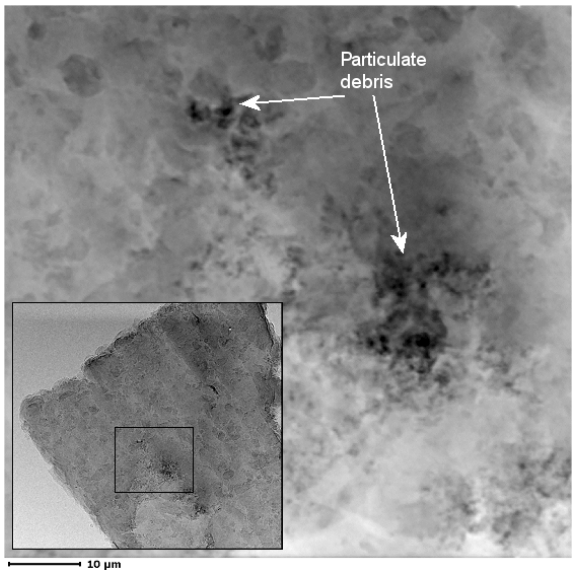

Fig 2: A phase retrieved image of the track terminal containing a number of micrometer fragments.

SEM/EDS Imaging & Analysis. It is also important to be able to distinguish between single mineral and heterogenous chondritic grains. While previous researchers have used synchrotron based X-ray analysis techniques for elemental characterization [e.g. 12], there are distinct benefits in using one instrument for all initial studies. Due to the nano-scale mineralogy of IDPs, studies have typically been based on transmission electron microscopes (TEM) rather than the SEM. However TEM requires electron transparent sections, unlike the SEM which can be used to examine bulk materials with little or no preparation. Using the microblade extraction technique, a portion of an impact track was recovered from a bulk ODC tile [17]. The 1mm diameter fragment of aerogel was mounted on a standard carbon conductive substrate and examined using a LEO 1455VP SEM fitted with an INCA energy dispersive X-ray spectrometer (EDS). Previously a significant problem with back-scattered electron (BSE) imaging has been difficulty in distinguishing silicate dominated micrometeoroid fragments from silica aerogel. This is because the compositional contrast is largely obscured by the rough track surface generated during extraction [16], creating a number of image artifacts. Because the microblades generate smoother surface cuts, this effect is dramatically reduced and enables the acquisition of a BSE image that identifies a number bright fragments within the exposed track (Fig. 3a). The bright fragments can then be characterized using EDS spot analysis (Fig. 3b) or X-ray elemental mapping. The combination of these techniques pinpoints the location of material within tracks and therefore greatly assists recovery.

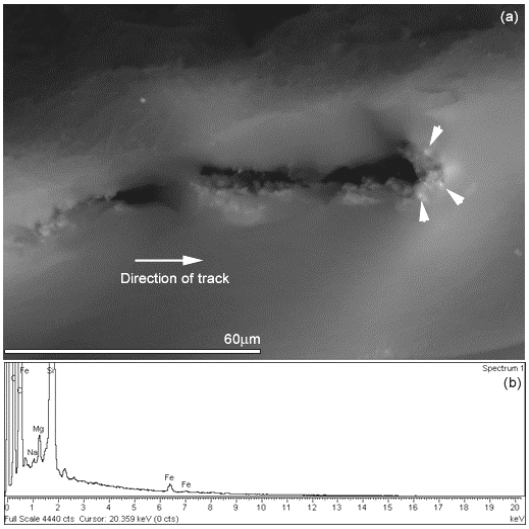

Fig 3: (a) BSE image of a track. The white indicators locate particulate debris. (b) EDS from one particle showing a probable silicate composition.

Conclusion: Electron beam detection techniques are well suited to locate and analyze micron and submicron chondritic debris preserved within impact tracks. These techniques in conjuction with micromanipulating capabilities of FIB microscopy [20] will enable *in-situ* recovery of Stardust particles.

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Acknowledgment: This work was performed in part under the auspices of the US Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48. This work was supported by NASA grants NNH04AB49I (JPB) and NAG5-119 (AJW).